ANSWERS: crystal ball questions on explaining properties of aqueous solutions

1) $NH_4Cl(aq)$ is solution **A**:
good conductor of electricity – it fully dissociates in solution into ammonium and chloride ions, which conduct electricity.
$NH_4Cl \rightarrow NH_4^+ + Cl^-$
Its pH is that of a weak acid, as the ammonium ion is a weak acid and partially dissociates in water, producing hydronium ions:
$NH_4^+ + H_2O \rightleftharpoons NH_3 + H_3O^+$

$NH_3(aq)$ is solution **B**:
its pH is that of a weak base as NH_3 is a weak base and it partially dissociates in water, producing hydroxide ions:
$NH_3 + H_2O \rightleftharpoons NH_4^+ + OH^-$
Poor conductor of electricity as it is only partially dissociated into ions in water.

$HCl(aq)$ is solution **C**:
low pH is that of a strong acid, HCl fully dissociates in water, producing hydronium ions:
$HCl + H_2O \rightarrow H_3O^+ + Cl^-$
Good conductor of electricity as it fully dissociates into ions in solution which conduct electricity.

2) $0.1 molL^{-1}$HCI, $0.01 molL^{-1}$ HCI, $0.01 molL^{-1}$ CH_3COOH, $0.01 molL^{-1}$ NaOH Highest pH.
HCl is a strong acid and is fully dissociated in water. It donates its protons readily to become completely dissociated.
$HCl + H_2O \rightarrow H_3O^+ + Cl^-$
The 0.1 mol L^{-1} HCl will produce 0.1 mol L^{-1} hydronium ion; the 0.01 mol L^{-1} HCl will produce 0.01 mol L^{-1} hydronium ion.
Hence the 0.1 mol L^{-1} HCl will have the lowest pH.
CH_3COOH is a weak acid and is only partially dissociated in water. Fewer protons are donated to water.
$CH_3COOH + H_2O \rightleftharpoons H_3O^+ + CH_3COO^-$
The 0.01 mol L^{-1} CH_3COOH will produce fewer protons, and hence lower $[H_3O^+]$ than 0.01 mol L^{-1} HCl; hence 0.01 mol L^{-1} HCl will have a lower pH than 0.01 mol L^{-1} CH_3COOH.
NaOH is a strong base and is fully dissociated in water. It accepts protons readily.
$NaOH \rightarrow Na^+ + OH^-$
For NaOH the concentration of hydroxide ion is greater than the concentration of hydronium ion, $[OH^-] > [H_3O^+]$. This solution has the highest pH.

3) $HNO_3 + H_2O \rightarrow NO_3^- + H_3O^+$
strong acid OR fully dissociates, produces high(er) conc. of ions, higher conductivity

$HCOOH + H_2O \rightleftharpoons HCOO^- + H_3O^+$
weak acid OR partially dissociates, producing low(er) conc. ions, hence lower conductivity

$KOH \rightarrow K^+ + OH^-$
Strong base OR fully soluble, produces high(er) conc. ions, higher conductivity

4) a) Weaker acid is HB

Acid strength is indicated by the ability to donate hydrogen ions. Strong acids are fully dissociated in solution and donate all the hydrogen ions. Weak acids are only partially dissociated in solution and donate only some hydrogen ions.

Acid HA has fully donated its protons as a pH of 3 indicates $[H_3O^+]$ of 0.00100 mol L^{-1}. Acid HB has only donated some of the hydrogen ions since a pH of 3.40 suggests a $[H_3O^+]$ of about 4×10^{-4} mol L^{-1} and since the actual acid concentration is 0.0100 mol L^{-1}, it is only partially dissociated and therefore the weak acid.

b) Sodium ethanoate dissolves in water, producing Na^+ ions and ethanoate ions, CH_3COO^-
$CH_3COONa(s) \longrightarrow CH_3COO^- + Na^+$
Then CH_3COO^- reacts with water/accepts a proton and produces OH^-
$CH_3COO^- + H_2O \rightleftharpoons CH_3COOH + OH^-$
The concentration of hydroxide ions, OH^-, has increased meaning $[OH^-] > [H_3O^+]$. The resulting solution is basic.

5) a) i) For HCl, the $[H_3O^+]$ is equal to [HCl].
HCl is a strong acid and completely dissociates in solution. Consequently the $[H_3O^+]$ is equal to [HCl].

ii) For CH_3COOH, $[H_3O^+]$ is less than $[CH_3COOH]$.
CH_3COOH is a weak acid and only partially dissociates in solution. Consequently, the $[H_3O^+]$ would be less than the concentration of the ethanoic acid.

b) Conductivity of NaOH and HCl are both high. Conductivity of CH_3COOH is low.
HCl is a strong acid and it completely dissociates into H_3O^+ and Cl^- ions. This means the conductivity will be high, as there will be a large concentration of ions in solution. NaOH is a strong base, and in solution is completely ionised to Na^+ ions and OH^- ions. Because there are a large concentration of ions in solution, the conductivity will be high. The conductivity of both these will be the same, as they have the same concentration of ions in solution.
Conductivity of CH_3COOH is low. CH_3COOH is a weak acid and only partially dissociates. Since there is a low concentration of ions, it will have low conductivity.

6) i) $\rightarrow$ $NH_3(aq)$ + $H_3O^+(aq)$
ii) $\rightarrow$ $F^-(aq)$ + $H_3O^+(aq)$

7) a) i) HB is circled

The strength of an acid is a measure of its ability to donate hydrogen ions.

Both acids react with water and donate H^+ ions to water.

$HA(aq) + H_2O \leftrightarrows H_3O^+(aq) + A^-(aq)$

$HB(aq) + H_2O \leftrightarrows H_3O^+(aq) + B^-(aq)$

OR

$[H_3O^+]$ from HA = $10^{-3.5} = 3.16 \times 10^{-4}$ mol L^{-1}.

$[H_3O^+]$ from HB = $10^{-1.8} = 1.58 \times 10^{-2}$ mol L^{-1}.

ii) The lower pH of acid HB means there is a higher concentration of H_3O^+ ions in the solution. As the acids are of the same concentration, the position of equilibrium lies further to the right for this acid. Thus more H^+ ions have been donated to water making HB a stronger acid.

b) i) Bubbles of gas are produced with both acids but this is more vigorous with HB.

Increase in temperature is noted in this reaction, and more heat is immediately produced by HB reaction.

Magnesium disappears/dissolves/consumed with both acids but in less time with HB.

ii) There is no (visual) change, but both acids require the same volume of sodium hydroxide to completely react.

Increase in temperature is noted in this reaction, and more heat is immediately produced by HB reaction.

c) Both acids react with magnesium as the reaction occurs between Mg and $H_3O^+(aq)$ ions.

$Mg + 2H_3O^+ \rightarrow Mg^{2+} + H_2(g) + 2H_2O$

OR $Mg + 2H^+ \rightarrow Mg^{2+} + H_2(g)$

Since H_2 gas is produced, bubbles are observed in each reaction. (The same volume of gas is produced with both acids, as the volume and concentration are the same). As $[H_3O^+(aq)]$ at equilibrium is greater in HB, there is increased collision rate with the Mg and so the reaction rate is increased, and the bubbles are formed more rapidly. As the reaction in HB is faster, the magnesium disappears in a shorter period of time.

The total amount of $H_3O^+(aq)$ ions available in each acid is the same, as the volume and concentration is the same. This means the volume of sodium hydroxide required to completely react with the acid will be the same.

$H_3O^+ + OH^- \rightarrow 2H_2O$

OR $H^+ + OH^- \rightarrow H_2O$

8) a) CO_3^{2-} (+ H_3O^+)

H_2CO_3 (+ OH^-)

b) Reaction B circled.

Formation of OH^- causes solution to be basic, and only reaction B produces this.

9) HCO_3^- It can donate **and** accept H^+

10) a) acid HA

Reaction rate of acid depends on concentration of hydrogen / hydronium ions – the higher the faster the reaction. Acid HA has the lowest pH therefore highest hydrogen / hydronium ion concentration.

b) acid HB

Acid strength is indicated by the ability to donate H^+ ions – the weakest acid is the poorest H^+ donor. Acid HA has fully donated H^+ ions since a pH of 1.00 indicates $[H^+]$ of 0.100 mol L^{-1}, which is the concentration of the acid.

Similarly acid HC has fully donated H+ ions since a pH of 3.00 indicates $[H^+]$ of 0.00100 mol L^{-1}, which is the concentration of the acid. These are both strong acids.

Acid HB has only donated some of the H^+ ions since a pH of 2.50 is $[H^+]$ of about 3 × 10−3 mol L^{-1} and the acid concentration is 0.100 mol L^{-1}, thus it is only partly dissociated and therefore the weakest acid.

11) Sodium ethanoate solution contains both $Na^+(aq)$ and $CH_3COO^-(aq)$ ions. Ethanoate ions react with water to accept H^+ since ethanoic acid is a weak acid. / ethanoate ions are weakly basic.

$CH_3COO^-(aq) + H_2O \rightleftharpoons CH_3COOH(aq) + OH^-(aq)$

So $[OH^-]$ has increased

The increase in $[OH^-]$ means there is a decrease in $[H_3O^{+]}$ (or $[H^+]$), which makes the solution basic so the pH is greater than 7

12) Propanoic acid is a weak acid which only partially dissociates in water. Therefore, it will have a relatively low concentration of H_3O^+, resulting in a higher pH, and low concentration of ions overall, resulting in a low conductivity.

Hydrochloric acid is a strong acid that fully dissociates in water. Therefore, it will have a high concentration of H_3O^+ and a lower pH, and a high concentration of ions overall, resulting in a high conductivity.